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Link et al.

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(54) **METHOD OF ADJUSTING DROP VOLUME**

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(51) **Int. Cl.**

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B41J 2/07	(2006.01)
B41J 2/03	(2006.01)
B41J 2/075	(2006.01)

(52) **U.S. Cl.**
CPC ... ***B41J 2/03*** (2013.01); ***B41J 2/075*** (2013.01)
USPC **347/11**; 347/74

(58) **Field of Classification Search**
USPC 347/11, 15, 73–75
See application file for complete search history.

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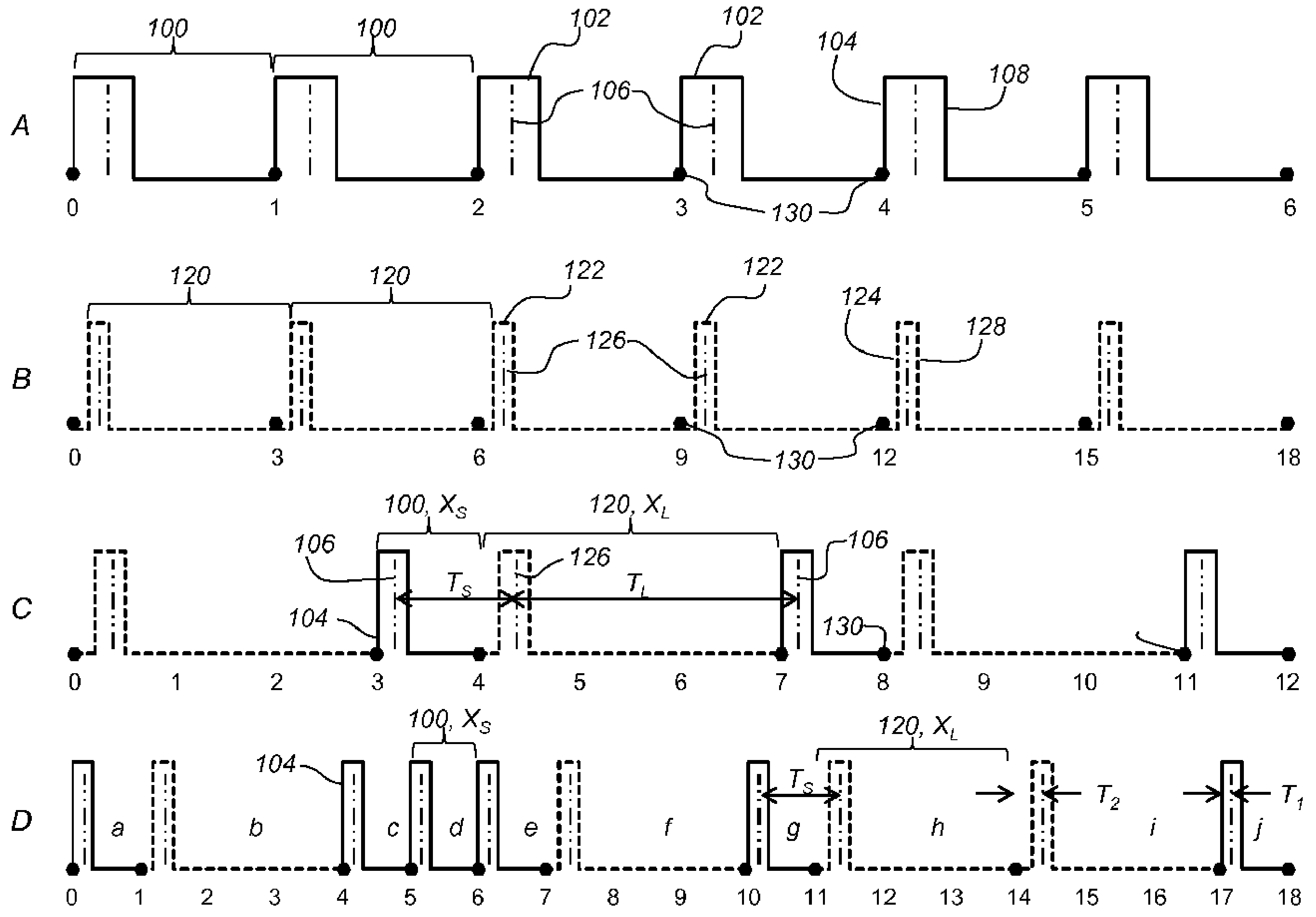
(57) **ABSTRACT**

A method for operating a jetting module includes applying to a drop forming mechanism a sequence of drop formation waveforms in which a small-drop waveform applied after another identical small-drop waveform causes a small drop of volume Vs to be formed; applying a large-drop waveform after another identical large-drop waveform causes a large drop of volume V_L to be formed, and applying a large-drop waveform adjacent to a small-drop waveform can be done in a way that produces a large drop having a volume V_{L2}, where V_{L2} is different than V_L and a small drop of volume V_{S2}, where V_{S2} is different than Vs.

14 Claims, 8 Drawing Sheets



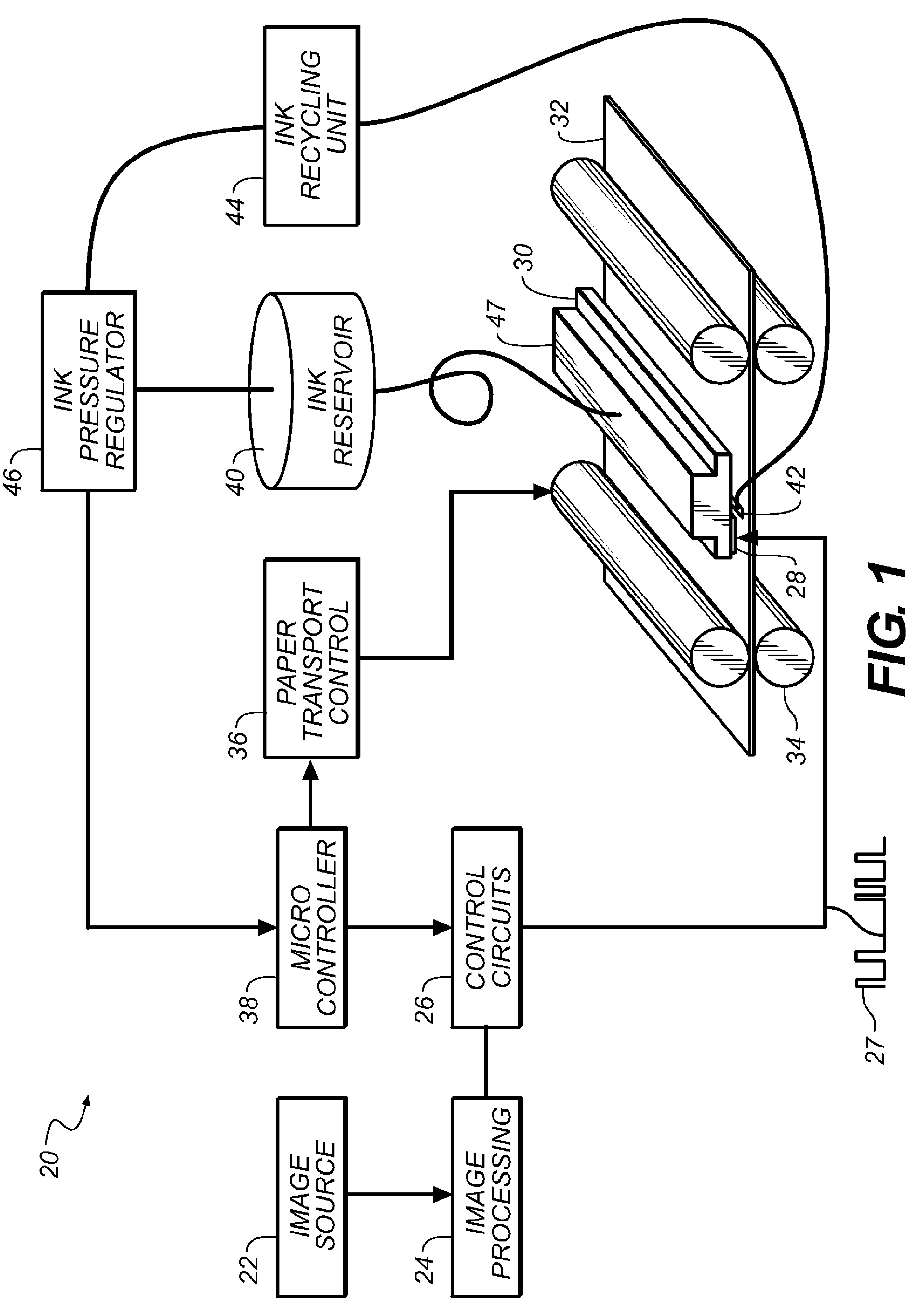

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IMAGE SOURCE
24
IMAGE PROCESSING
38
MICRO CONTROLLER
26
CONTROL CIRCUITS
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36
PAPER TRANSPORT CONTROL
46
INK PRESSURE REGULATOR
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INK RESERVOIR
44
INK RECYCLING UNIT
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FIG. 1

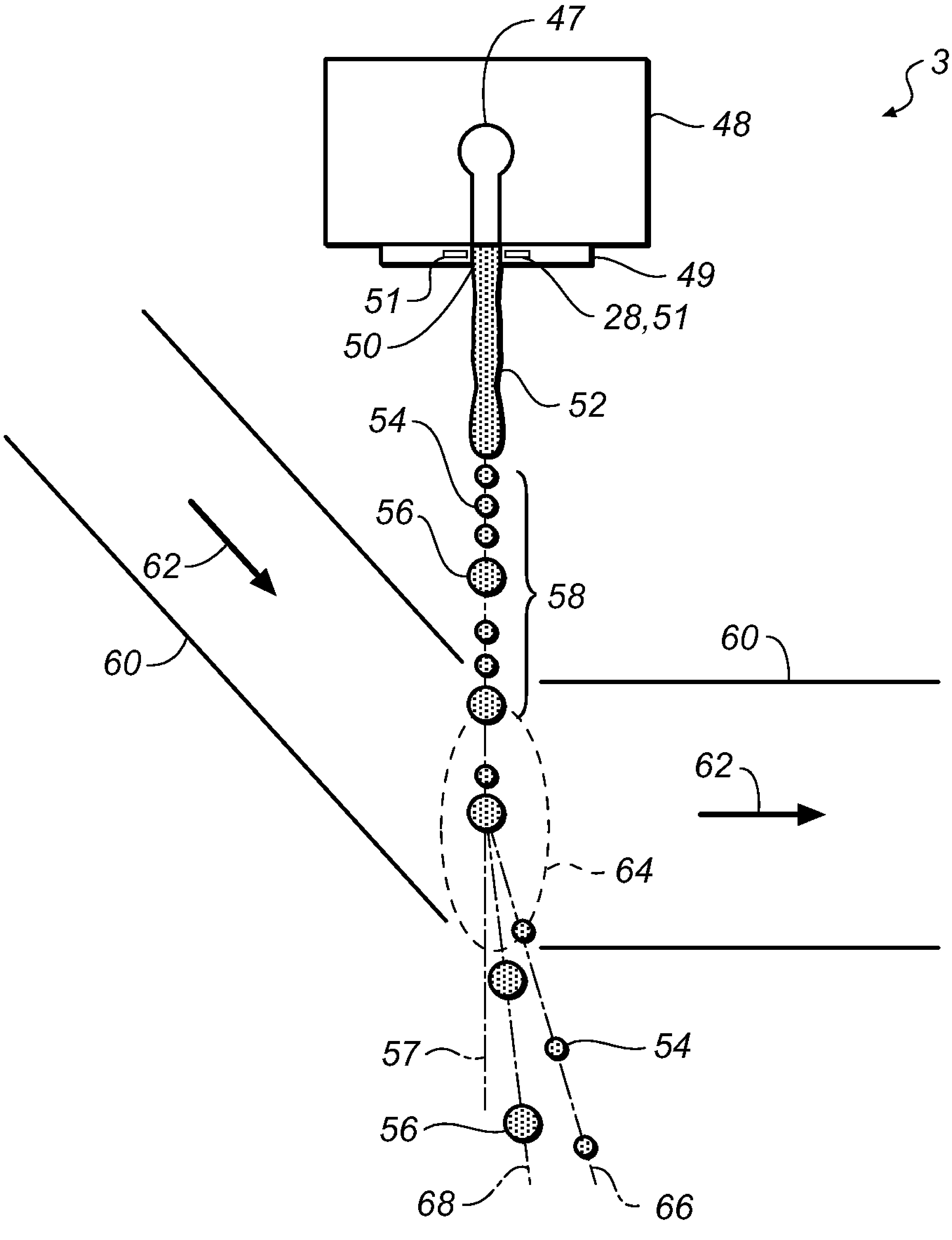
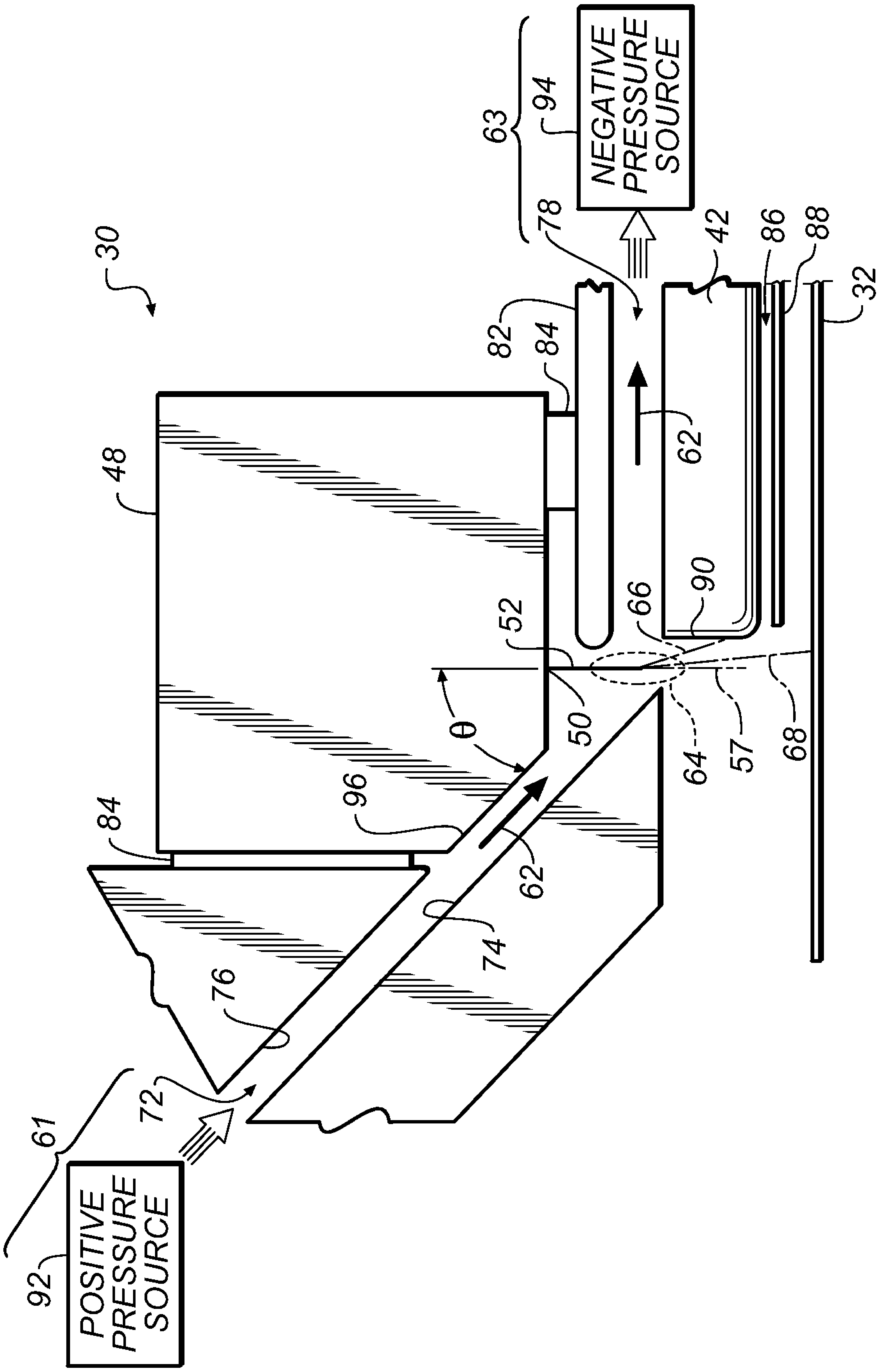


FIG. 2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NEGATIVE PRESSURE SOURCE
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POSITIVE PRESSURE SOURCE

FIG. 3

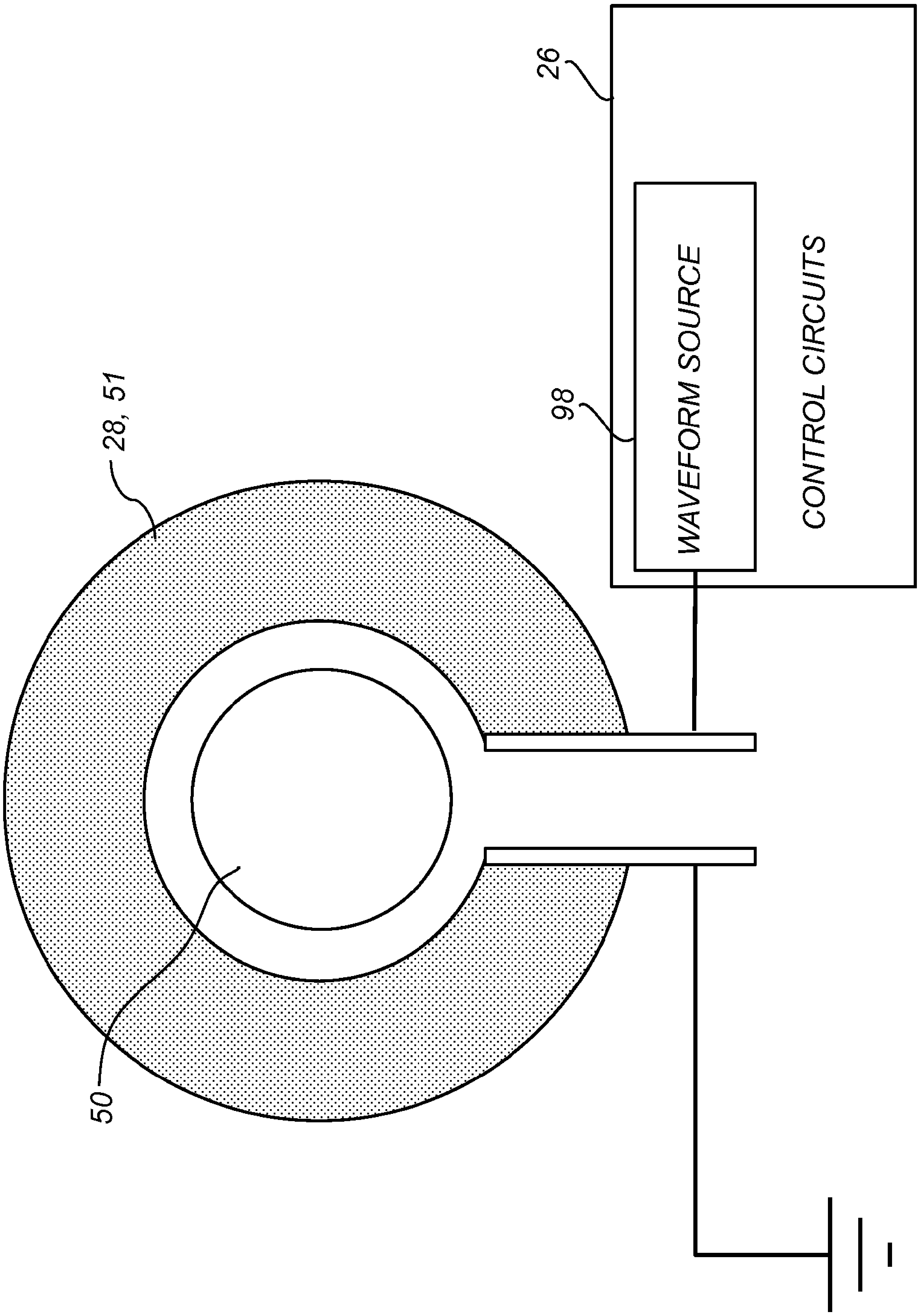


FIG. 4

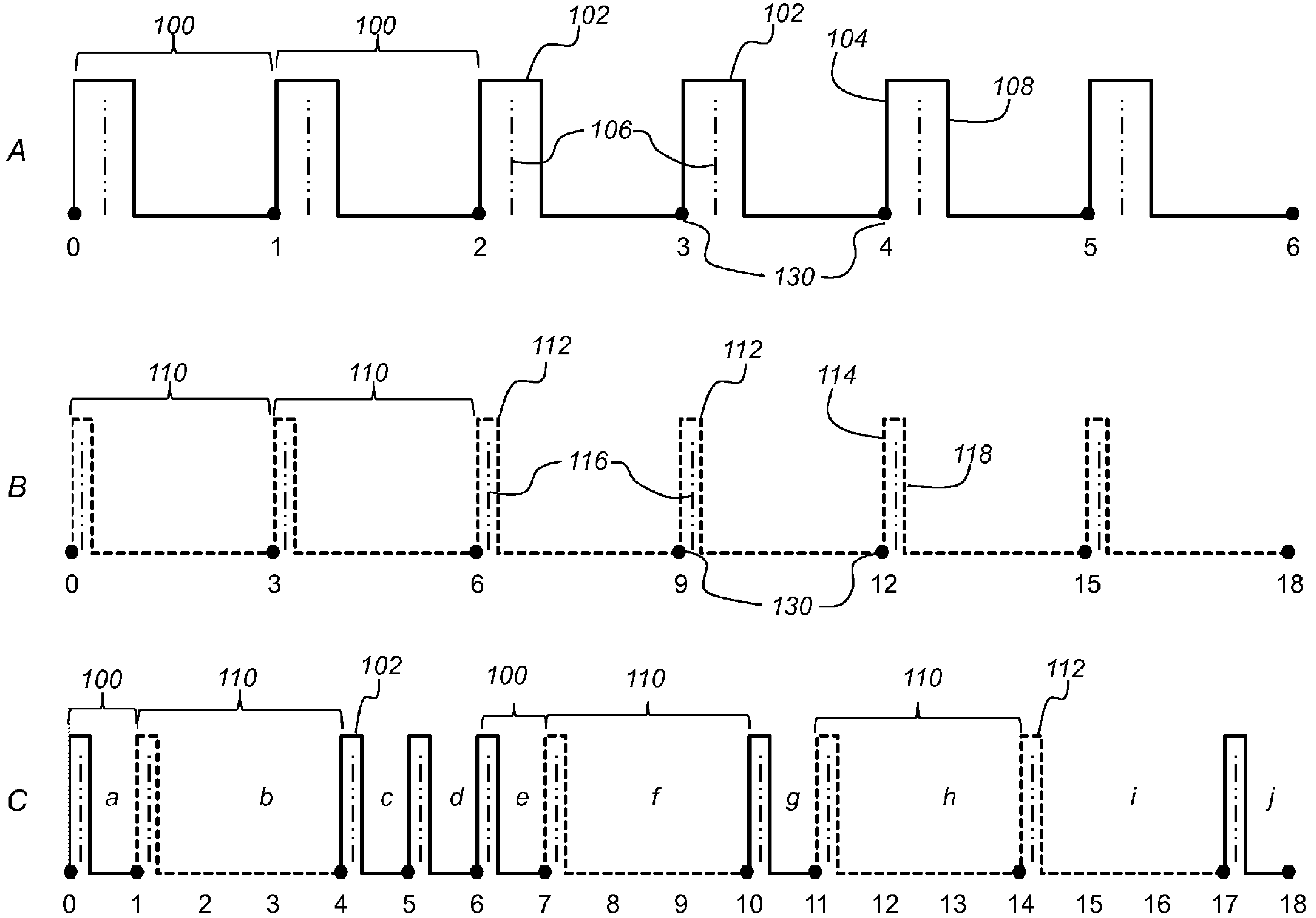
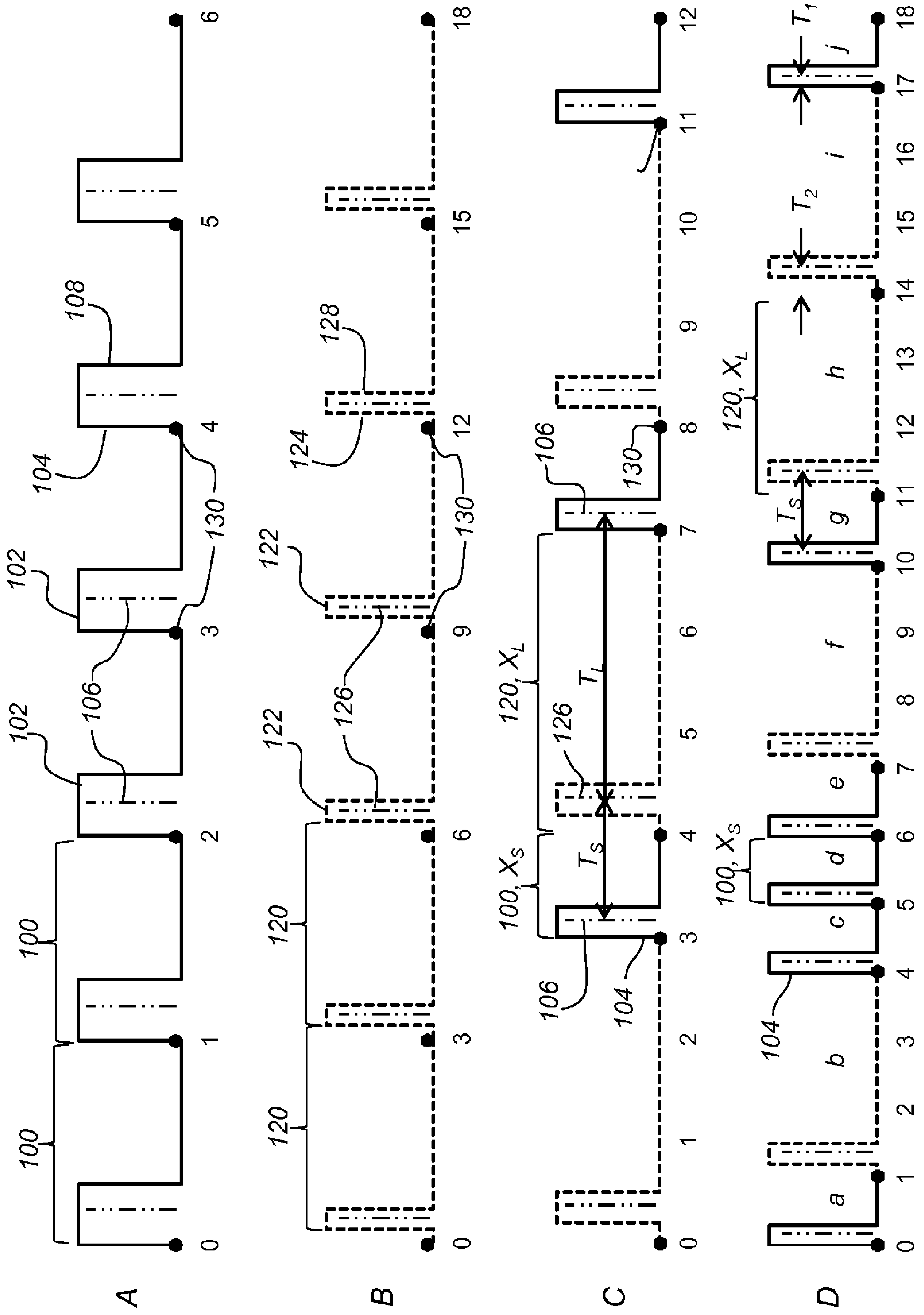


FIG. 5
(Prior Art)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120, X_L
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FIG. 6

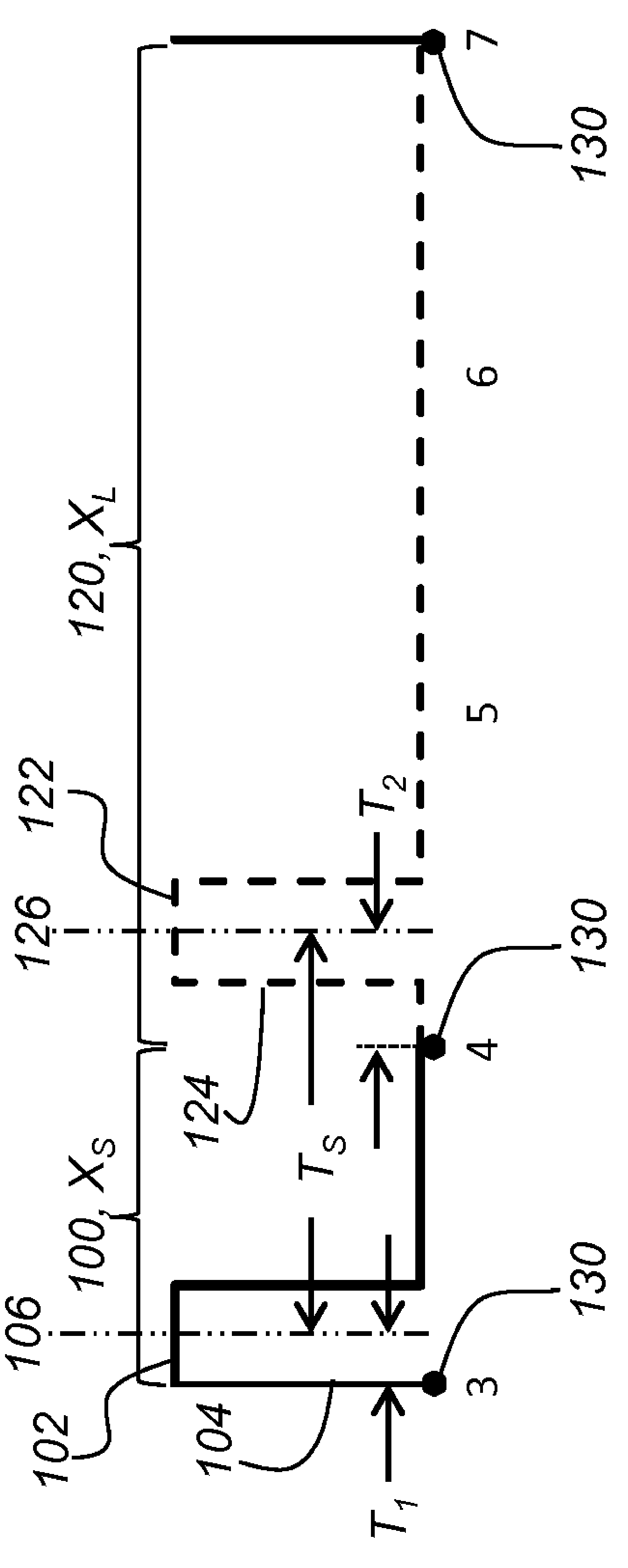

FIG. 7

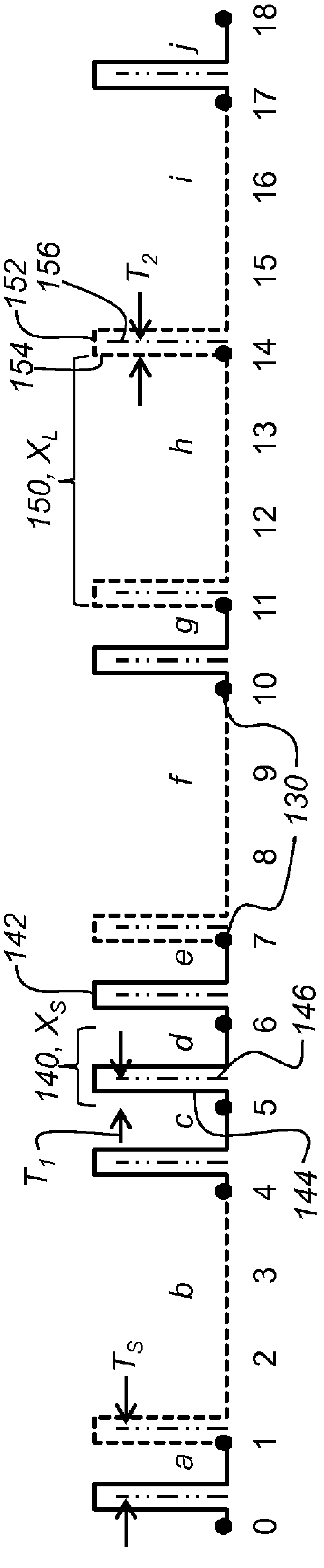

FIG. 8

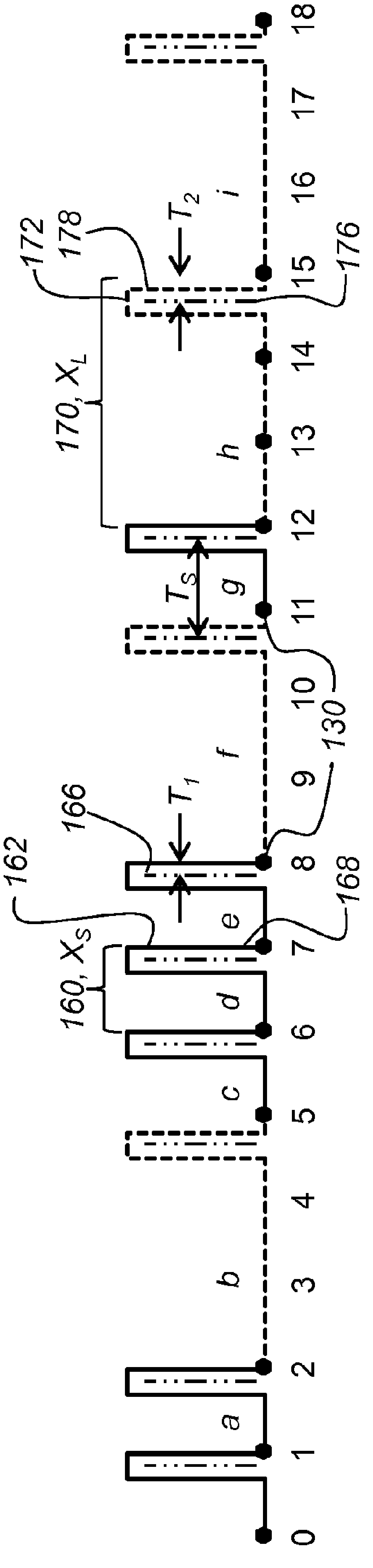

FIG. 9

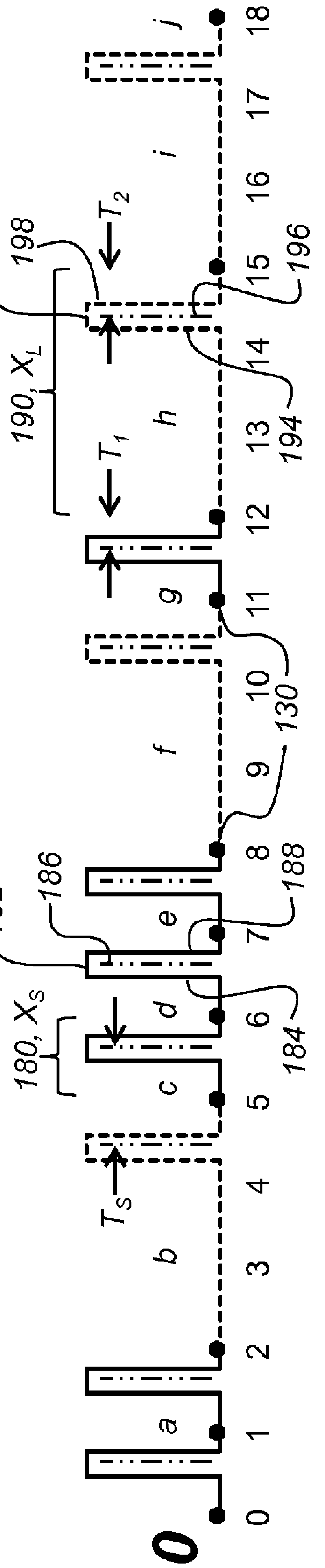

FIG. 10

METHOD OF ADJUSTING DROP VOLUME

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 61/608,674, filed Mar. 9, 2012, entitled "Method for Altering Drop Size in a Continuous Inkjet Printer" by Robert Link et al, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

This invention relates generally to the field of digitally controlled printing devices, and in particular to continuous printing systems in which a liquid stream is selectively broken off into drops having a small volume and drops having a large volume.

BACKGROUND OF THE INVENTION

Printing systems that deflect drops using a gas flow are known; see, for example, U.S. Pat. No. 4,068,241, issued to Yamada, on Jan. 10, 1978. Such printing systems rely on the ability to generate distinct sizes of drop—a "print drop" of a given size, and a "catch drop" of distinctly different size. Differential deflection of the drops of different sizes is employed to cause print drops to impinge on the substrate and the catch drops to be collected and re-circulated through the ink delivery system.

In thermally stimulated continuous inkjet printing (see, for example Jeanmaire et al. U.S. Patent Application Publication No. 20020085071 A1 and Chwalek et al, In U.S. Pat. No. 6,079,821), periodic heat pulses are applied to individual heaters embedded in a nozzle array. The periodic heat pulses drive capillary break-up of jets formed at each nozzle to produce an array of drops. The period of the pulse waveform determines the ultimate size of drop formed after jet break-up. Because the jet responds most sensitively to disturbances at a characteristic frequency f_R known as the Rayleigh frequency, drops are most effectively produced at a fundamental size corresponding to a volume of fluid given by $\pi r^2 U/f_R$, where r is the jet radius and U is the jet velocity.

In U.S. Pat. No. 6,851,796, which issued on Feb. 8, 2005, an ink drop forming mechanism selectively creates a stream of ink drops having a plurality of different volumes traveling along a first path. An air flow directed across the stream of ink drops interacts with the stream of ink drops. This interaction deflects smaller drops more than larger drops and thereby separates ink drops having one volume from ink drops having other volumes.

As the drop selection mechanism described above depends on drop size, it is necessary for large-volume drops to be fully formed before being exposed to the deflection air flow. Consider, for example, a case where the large-volume drop is to have a volume equal to four small-volume drops. It is often seen during drop formation that the portion of the ink stream that is to form the large-volume drop will separate from the main stream as desired, but will then break apart before coalescing to form the large-volume drop. It is necessary for this coalescence to be complete prior to passing through the drop deflecting air flow. Otherwise the separate fragments that are to form the large-volume drop will be deflected by an amount greater than that of a single large-volume drop. Similarly, the small-volume drops must not merge in air before having past the deflection air flow. If separate small-volume drops merge, they will be deflected less than desired.

The distance over which the large-volume drop forms upon coalescence of is fragments is known as the drop formation length (DFL), denoted herein as L_D. The details of the large-drop waveform and the physical properties of the jet determine the size of L_D. For the purposes of printing, smaller drop formation lengths are advantageous, as the drops are then available for size separation at distances closer to the nozzle plate, and the distance over which the drops must travel prior to separation is reduced. Thus a smaller drop formation length helps reduce the size of the printhead and reduces the risk of incomplete large drop formation and reduces the risk of unintended merging of small drops.

It has been found that ink coverage levels are excessive when printing on certain print media, resulting loss of acuity and discernable gray levels. While the ink coverage level can be reduced through the use of smaller nozzles or by reducing the ink pressure or increasing the frequency of drop formation, these options have shortcomings. Conversely, on other substrates the ink coverage levels can be insufficient, resulting in lack of optical density and voids in the printed regions. While the ink coverage level can be altered through the use of different nozzles sizes or by adjusting the ink pressure or the frequency of drop formation, these options can also have shortcomings. If different nozzle sizes are to be used for different print media, then it would be necessary to produce and maintain an inventory of a number of distinct printheads each having a distinct nozzle size. Reducing the ink pressure or raising the frequency of drop formation can result in reducing the stimulation perturbation wavelengths toward the Rayleigh cutoff limit. As the perturbation wavelengths are reduced toward the Rayleigh cutoff limit, the drop formation can become excessively sensitive to small changes in ink properties, nozzle size, ink pressure, and stimulation amplitude. Increasing the ink pressure or reducing the frequency, on the other hand, can increase the formation of satellite drops, which can reduce printhead reliability.

Thus there is a need for waveforms that provide a means to alter the size of the large drops relative to the small drops. The present invention addresses these needs.

SUMMARY OF THE INVENTION

The present invention is directed to overcoming one or more of the problems set forth above. Briefly summarized, according to one aspect of the invention, the invention resides in a method for operating a jetting module comprising providing a jetting module including a nozzle and a drop forming mechanism; providing a liquid to the jetting module under pressure sufficient to cause a liquid stream to jet from the nozzle; providing a small-drop waveform, the small-drop waveform having a starting endpoint and a trailing endpoint, the time between the starting endpoint and the trailing endpoint being the small-drop period X_S, the small-drop waveform including a small drop volume-control pulse, the small-drop volume-control pulse having a centroid, the centroid of the small-drop volume-control pulse being at a first defined time relative to a predefined one of the starting endpoint and the trailing endpoint of the small-drop waveform; providing a large-drop waveform, the large-drop waveform having a starting endpoint and a trailing endpoint, the time between the starting endpoint and the trailing endpoint being the large-drop period X_L, where $X_L = N * X_S$ and N is an integer greater than one, the large-drop waveform including a large-drop volume-control pulse, the large-drop volume-control pulse having centroid; wherein the centroid of the large-drop volume-control pulse being at a second defined time relative to the corresponding one of the starting endpoint and the trailing endpoint of the large-drop waveform, the second defined time being different from the first defined time; applying to the drop forming mechanism a sequence of drop formation waveforms in which a small-drop waveform applied after another identical small-drop waveform causes a small drop of volume Vs to be formed; applying a small-drop waveform after a large-drop waveform causes a small drop of volume Vs2 to be formed, where V_{S2} is not equal to V_S; applying a large-drop waveform after another identical large-drop waveform causes a large drop of volume VL to be formed, where $V_L \sim N^*Vs$; and applying a large-drop waveform after a small-drop waveform causes a large drop of volume VL2 to be formed, where V_{L2} is not equal to V_L.

BRIEF DESCRIPTION OF THE DRAWINGS

In the detailed description of the example embodiments of the invention presented below, reference is made to the accompanying drawings, in which:

FIG. **1** shows a simplified block schematic diagram of an example embodiment of a printer system made in accordance with the present invention;

FIG. **2** is a schematic view of an example embodiment of a continuous printhead made in accordance with the present invention;

FIG. **3** is a schematic view of a simplified gas flow deflection mechanism of the present invention;

FIG. **4** is a drop forming device and control circuits associated with the nozzle;

FIGS. **5***a-c* are prior art waveforms for creating large and small drops;

FIGS. **6***a-d* are waveforms of the present invention for creating large and small drops;

FIG. **7** is an enlarged view of a portion of FIG. **6***c;*

FIG. **8** is a waveform of the present invention for creating large and small drops according to other embodiments of the present invention;

FIG. **9** is a waveform of the present invention for creating large and small drops according to another embodiment of the present invention; and

FIG. **10** is a waveform of the present invention for creating large and small drops according to a final embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present description will be directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the present invention. It is to be understood that elements not specifically shown or described can take various forms well known to those skilled in the art. In the following description and drawings, identical reference numerals have been used, where possible, to designate identical elements.

The example embodiments of the present invention are illustrated schematically and not to scale for the sake of clarity. One of the ordinary skills in the art will be able to readily determine the specific size and interconnections of the elements of the example embodiments of the present invention.

As described herein, the example embodiments of the present invention provide a printhead or printhead components typically used in inkjet printing systems. However, many other applications are emerging which use inkjet printheads to emit liquids (other than inks) that need to be finely metered and deposited with high spatial precision. As such, as described herein, the terms "liquid" and "ink" refer to any material that can be ejected by the printhead or printhead components described below.

Referring to FIGS. **1**, **2** and **3**, example embodiments of a printing system and a continuous printhead are shown that include the present invention described below. It is contemplated that the present invention also finds application in other types of printheads or jetting modules including, for example, drop on demand printheads and other types of continuous printheads.

Referring to FIG. **1**, a continuous printing system **20** includes an image source **22** such as a scanner or computer which provides raster image data, outline image data in the form of a page description language, or other forms of digital image data. This image data is converted to half-toned bitmap image data by an image processing unit **24** which also stores the image data in memory. A plurality of drop forming mechanism control circuits **26** read data from the image memory and apply drop formation waveforms **27**, typically a sequence of time-varying electrical pulses, to a drop forming mechanism(s) **28** that are associated with one or more nozzles of a printhead **30**. These pulses are applied at an appropriate time, and to the appropriate nozzle, so that drops formed from a continuous ink jet stream will form spots on a recording medium **32** in the appropriate position designated by the data in the image memory.

Recording medium **32** is moved relative to printhead **30** by a recording medium transport system **34**, which is electronically controlled by a recording medium transport control system **36**, and which in turn is controlled by a micro-controller **38**. The recording medium transport system **34** shown in FIG. **1** is a schematic only, and many different mechanical configurations are possible. For example, a transfer roller could be used as recording medium transport system **34** to facilitate transfer of the ink drops to recording medium **32**. Such transfer roller technology is well known in the art. In the case of page width printheads, it is most convenient to move recording medium **32** past a stationary printhead **30**. In the case of scanning print systems, it is usually most convenient to move the printhead **30** along one axis (the sub-scanning direction) and the recording medium **32** along an orthogonal axis (the main scanning direction) in a relative raster motion.

Ink is contained in an ink reservoir **40** under pressure. In the non-printing state, continuous ink jet drop streams are unable to reach recording medium **32** due to an ink catcher **42** that blocks the stream and which can permit a portion of the ink to be recycled by an ink recycling unit **44**. The ink recycling unit **44** reconditions the ink and feeds it back to reservoir **40**. Such ink recycling units **44** are well known in the art. The ink pressure suitable for optimal operation will depend on a number of factors, including geometry and thermal properties of the nozzles and thermal properties of the ink. A constant ink pressure can be achieved by applying pressure to ink reservoir **40** under the control of ink pressure regulator **46**. Alternatively, the ink reservoir **40** can be left unpressurized, or even under a reduced pressure (vacuum), and a pump is employed to deliver ink from the ink reservoir **40** under pressure to the printhead **30**. In such an embodiment, the ink pressure regulator **46** can include an ink pump control system. As shown in FIG. **1**, catcher **42** is a type of catcher commonly referred to as a "knife edge" catcher.

The ink is distributed to printhead **30** through an ink channel **47**. The ink preferably flows through slots or holes etched through a silicon substrate of printhead **30** to its front surface, where a plurality of nozzles and drop forming mechanisms, for example, heaters, are situated. When printhead **30** is fabricated from silicon, drop forming mechanism control circuits **26** can be integrated with the printhead **30**. Printhead **30** also includes a deflection mechanism (not shown in FIG. **1**) which is described in more detail below with reference to FIGS. **2** and **3**.

Referring to FIG. **2**, a schematic view of continuous liquid printhead **30** is shown. A jetting module **48** of printhead **30** includes an array or a plurality of nozzles **50** formed in a nozzle plate **49**. In FIG. **2**, nozzle plate **49** is affixed to jetting module **48**. However, as shown in FIG. **3**, nozzle plate **49** can be an integral portion of the jetting module **48**.

Liquid, for example, ink, is emitted under pressure through each nozzle **50** of the array to form filaments of liquid **52**. In FIG. **2**, the array or plurality of nozzles **50** extends into and out of the figure.

Jetting module **48** is operable to form liquid drops having a first size or volume and liquid drops having a second size or volume through each nozzle **50**. To accomplish this, jetting module **48** includes a drop stimulation device **28**, also commonly called a drop forming device, for example, a heater or a piezoelectric actuator, that, when selectively activated, perturbs each filament of liquid **52**, for example, ink, to induce portions of each filament to breakoff from the filament and coalesce to form drops **54**, **56**.

In FIG. **2**, drop forming device **28** is a heater **51**, for example, an asymmetric heater or a ring heater (either segmented or not segmented), located in the nozzle plate **49** on one or both sides of nozzle **50**. This type of drop formation is known and has been described in, for example, U.S. Pat. No. 6,457,807 B1, issued to Hawkins et al., on Oct. 1, 2002; U.S. Pat. No. 6,491,362 B1, issued to Jeanmaire, on Dec. 10, 2002; U.S. Pat. No. 6,505,921 B2, issued to Chwalek et al., on Jan. 14, 2003; U.S. Pat. No. 6,554,410 B2, issued to Jeanmaire et al., on Apr. 29, 2003; U.S. Pat. No. 6,575,566 B1, issued to Jeanmaire et al., on Jun. 10, 2003; U.S. Pat. No. 6,588,888 B2, issued to Jeanmaire et al., on Jul. 8, 2003; U.S. Pat. No. 6,793,328 B2, issued to Jeanmaire, on Sep. 21, 2004; U.S. Pat. No. 6,827,429 B2, issued to Jeanmaire et al., on Dec. 7, 2004; and U.S. Pat. No. 6,851,796 B2, issued to Jeanmaire et al., on Feb. 8, 2005.

As discussed in these references, the volume of the drops formed by the activation of the drop forming device depends on the frequency or period of activation of the heater. A high frequency of activation of the drop forming device results in small-volume drops being formed and a low frequency of activations results in the formation of large-volume drops. When drop forming activation pulses are applied to the drop forming device, the drop forming devices perturb the liquid stream flowing past the drop forming device. The perturbation travels with the liquid of the liquid stream, to form a point where the jet pinches off to separate a newly formed drop from the rest of the jet. As the time interval between successive drop forming activation pulses increases, the length of the liquid stream between the resultant pinch points increases, yielding a drop of increased volume. Depending on the time intervals between activation pulses in this manner, large-volume drops and small-volume drops of any desired volume ratio can be created, ranging up to 10:1.

Typically, one drop forming device **28** is associated with each nozzle **50** of the nozzle array. A drop forming device **28** can be associated with groups of nozzles **50** or all of nozzles **50** of the nozzle array. FIG. **4** is a plan view of a portion of the nozzle plate **49** showing the nozzle **50** with an associated drop formation device **28**, according to one embodiment of the invention. The drop forming device **28** is a single drop forming transducer that substantially surrounds the nozzle. The drop forming transducer can be one of a heater, piezoelectric transducer, electrohydrodynamic stimulation device, thermal actuator or any other drop forming transducer. In response to a drop forming waveform supplied to the drop forming transducer, it acts on one of the nozzles **50**, the liquid passing through the nozzle **50**, or the liquid jet flowing from the nozzle **50** to introduce a perturbation to the liquid jet such that the perturbation can grow to cause a drop **54**, **56** to break off from the liquid jet. The drop forming transducer substantially surrounds the nozzle **50** so that as it acts on the liquid passing through the nozzle **50** and it doesn't substantially alter the directionality of the liquid jet.

When printhead **30** is in operation, drops **54**, **56** are typically created in a plurality of sizes or volumes, for example, in the form of large drops **56**, a first size or volume, and small drops **54**, a second size or volume from each of the nozzles **50** in the nozzle array. A drop stream **58** including drops **54**, **56** follows a drop path or trajectory **57**.

Printhead **30** also includes a gas flow deflection mechanism **60** that directs a flow of gas **62**, for example, air, past a portion of the drop trajectory **57**. This portion of the drop trajectory **57** is called the deflection zone **64**. As the flow of gas **62** interacts with drops **54**, **56** in deflection zone **64** it alters the drop trajectories. As the drop trajectories pass out of the deflection zone **64** they are traveling at an angle, called a deflection angle, relative to the undeflected drop trajectory **57**.

Small drops **54** are more affected by the flow of gas than are large drops **56** so that the small drop trajectory **66** diverges from the large drop trajectory **68**. That is, the deflection angle for small drops **54** is larger than for large drops **56**. When the volume ratio between the large-volume drops **56** and the small-volume drops **54** is greater than 2:1, the flow of gas **62** provides sufficient drop deflection and therefore sufficient divergence of the small and large drop trajectories **66**, **68** so that catcher **42** (shown in FIGS. **1** and **3**) can be positioned to intercept one of the small drop trajectory **66** and the large drop trajectory **68** so that drops **54**, **56** following the drop trajectory **66**, **68** are collected by catcher **42** while drops **54**, **56** following the other drop trajectory **66**, **68** bypass the catcher and impinge the recording medium **32** (shown in FIGS. **1** and **3**).

When catcher **42** is positioned to intercept large drop trajectory **68**, small drops **54** are deflected sufficiently to avoid contact with catcher **42** and strike the print media. As the small drops **54** are printed, this is called small drop print mode. When catcher **42** is positioned to intercept small drop trajectory **66**, large drops **56** are the drops that print. This is referred to as large drop print mode.

Referring to FIG. **3**, jetting module **48** includes an array or a plurality of nozzles **50**. Liquid, for example, ink, supplied through channel **47**, is emitted under pressure through each nozzle **50** of the array to form filaments of liquid **52**. In FIG. **3**, the array or plurality of nozzles **50** extends into and out of the figure.

Drop stimulation device **28**, also called a drop forming device or drop forming mechanism, (shown in FIGS. **1** and **2**) associated with jetting module **48** is selectively actuated to perturb the filament of liquid **52** to induce portions of the filament to break off from the filament to form drops. The selective activation of the drop forming device **28** occurs in response to drop formation waveforms **27** received from a waveform source **98**, which is a portion of the control circuits **26**. The waveform source typically creates a sequence of drop formation waveforms **27** based on the dot pattern to be printed. Each waveform has a starting endpoint and a trailing endpoint. The time between the starting endpoint of a waveform and the trailing endpoint of the waveform is equal to the period of the waveform. In the sequences of waveforms, the trailing endpoint of a waveform is coincident with the starting endpoint of the subsequent waveform; therefore a single reference number **130** will be used as reference for both the starting endpoints and the trailing endpoints throughout the application. Each waveform has period or time duration. The sequence of waveforms from the waveform source consists of one or more waveforms for the creation of small drops, called small-drop waveforms, and one or more waveforms for the creation of large drops, called large-drop waveforms. Each of the one or more small-drop waveforms and each of the one or more large-drop waveforms include a drop forming pulse. The drop forming pulse of each waveform, when applied to the drop forming device **28**, creates a perturbation of the filament of liquid **52**. The perturbation created by the drop forming pulse grows becoming a pinch point at which the liquid filament breaks, separating a liquid drop from the rest of the filament. The drop forming pulse of a waveform controls the break-up point and drop formation boundary between the drop formed by the waveform and the drop to be formed by the next drop forming waveform. The time interval between the drop forming pulses controls the spacing along the filament between the pinch points, and thereby controls the volume of the created drop, the large drop volume control pulse controls the jet break-up point and drop formation boundary between the large-drop and it's adjacent small or large drop The drop forming pulses are also called volume-control pulses. As discussed in U.S. Pat. No. 7,828,420, a drop formation waveform **27** can include one or more additional pulses in addition to the drop forming pulse. These one or more additional pulses don't create drop breakoff pinch points but they can influence the drop formation length and other characteristics of the drop formation process. A sequence of drops is created in the form of large drops and small drops that travel toward the recording medium **32** according to the supplied sequence of large drop and small-drop waveforms.

Positive pressure gas flow structure **61** of gas flow deflection mechanism **60** is located on a first side of drop trajectory **57**. Positive pressure gas flow structure **61** includes first gas flow duct **72** that includes a lower wall **74** and an upper wall **76**. Gas flow duct **72** directs gas flow **62** supplied from a positive pressure source **92** at downward angle θ of approximately a 45° relative to liquid filament **52** toward drop deflection zone **64** (also shown in FIG. **2**). An optional seal(s) **84** provides an air seal between jetting module **48** and upper wall **76** of gas flow duct **72**.

Upper wall **76** of gas flow duct **72** does not need to extend to drop deflection zone **64** (as shown in FIG. **2**). In FIG. **3**, upper wall **76** ends at a wall **96** of jetting module **48**. Wall **96** of jetting module **48** serves as a portion of upper wall **76** ending at drop deflection zone **64**.

Negative pressure gas flow structure **63** of gas flow deflection mechanism **60** is located on a second side of drop trajectory **57**. Negative pressure gas flow structure **63** includes a second gas flow duct **78** located between catcher **42** and an upper wall **82** that exhausts gas flow **62** from deflection zone **64**. Second duct **78** is connected to a negative pressure source **94** that is used to help remove gas flowing through second duct **78**. An optional seal(s) **84** provides an air seal between jetting module **48** and upper wall **82**.

As shown in FIG. **3**, gas flow deflection mechanism **60** includes positive pressure source **92** and negative pressure source **94**. However, depending on the specific application contemplated, gas flow deflection mechanism **60** can include only one of positive pressure source **92** and negative pressure source **94**.

Gas supplied by first gas flow duct **72** is directed into the drop deflection zone **64**, where it causes large drops **56** to follow large drop trajectory **68** and small drops **54** to follow small drop trajectory **66**. As shown in FIG. **3**, small drop trajectory **66** is intercepted by a front face **90** of catcher **42**. Small drops **54** contact face **90** and flow down face **90** and into a liquid return duct **86** located or formed between catcher **42** and a plate **88**. Collected liquid is either recycled and returned to ink reservoir **40** (shown in FIG. **1**) for reuse or discarded. Large drops **56** bypass catcher **42** and travel on to recording medium **32**. Alternatively, catcher **42** can be positioned to intercept large drop trajectory **68**. Large drops **56** contact catcher **42** and flow into a liquid return duct located or formed in catcher **42**. Collected liquid is either recycled for reuse or discarded. Small drops **54** bypass catcher **42** and travel on to recording medium **32**.

Alternatively, deflection can be accomplished by applying heat asymmetrically to filament of liquid **52** using an asymmetric heater **51**. When used in this capacity, asymmetric heater **51** typically operates as the drop forming mechanism **28** in addition to the deflection mechanism. This type of drop formation and deflection is known having been described in, for example, U.S. Pat. No. 6,079,821, issued to Chwalek et al., on Jun. 27, 2000.

Deflection can also be accomplished using an electrostatic deflection mechanism. The electrostatic deflection mechanism can facilitate drop charging and drop deflection using a single electrode per jet, like the one described in U.S. Pat. No. 4,636,808, or through the use of separate drop charging and drop deflection electrodes. Typically an individual drop charging electrode is associated with each jet, as described in U.S. Pat. No. 4,636,808. Alternative electrostatic deflection mechanisms use a single drop charging electrode for an array of nozzles, as described in U.S. Pat. No. 7,938,516 or U.S. Published Application No. 20100033542.

As shown in FIG. **3**, catcher **42** is a type of catcher commonly referred to as a "Coanda" catcher. However, the "knife edge" catcher shown in FIG. **1** and the "Coanda" catcher shown in FIG. **3** are interchangeable and either can be used usually the selection depending on the application contemplated. Alternatively, catcher **42** can be of any suitable design including, but not limited to, a porous face catcher, a delimited edge catcher, or combinations of any of those described above.

In typical printheads, the jetting module **48** contains a large number of nozzles **50**, each with an associated drop forming device **28**. Each drop forming device **28** receives sequences of drop formation waveforms **27** from a corresponding waveform source **98**. The drop formation waveforms **27** typically are waveforms of the voltage applied to the drop forming device **28**. Alternatively the drop formation waveforms **27** can be waveforms of the current applied to the drop forming device **28**. While the drop forming device can be actuated to form large drops and small drops of any desired volume ratio up to 10:1, including both integer and non-integer ratios, the mechanism control circuits **26** containing the waveform sources **98** for the array of drop forming devices **28** become unacceptably complex if the periods of the one or more large-drop waveforms are not all equal to each other. Similarly, the periods of the one or more small-drop waveforms should also be equal to each other to avoid inacceptable control circuit complexity. Furthermore to avoid unacceptable complexity in the control circuits, the period of the large-drop waveforms should be equal to the period of the small-drop waveforms times an integer N; $2 \leq N \leq 10$. In prior art systems having arrays of nozzles and independent drop selection per nozzle, these limitations on the periods of the large-drop waveforms and the small-drop waveforms have restricted the volume ratio of large-volume drops to small-volume drops to integer values.

The present invention overcomes this limitation of the art by providing a jetting module **48** including a nozzle **50** and a drop forming mechanism **28**; providing a liquid to the jetting module **48** under pressure sufficient to cause a liquid stream to jet from the nozzle **50**; providing a small-drop waveform, the small drop waveform having a starting endpoint and a trailing endpoint, the small-drop waveform having a small-drop period X_S, the small-drop waveform including a small drop volume-control pulse, the small-drop volume-control pulse of the small-drop volume-control pulse having centroid, the centroid of the small-drop volume-control pulse being at a first defined time relative a predefined one of the starting endpoint and the trailing endpoint of the small-drop waveform; providing a large-drop waveform, the large-drop waveform having a starting endpoint and a trailing endpoint, the large-drop waveform having a large-drop period X_L, where $X_L=N*X_S$ and N is an integer greater than one, the large-drop waveform including a large-drop volume-control pulse, the large-drop volume-control pulse having centroid; wherein the centroid of the large-drop volume-control pulse being at a second defined time relative to the corresponding one of the starting endpoint and the trailing endpoint, the second defined time being different from the first defined time; applying to the drop forming mechanism a sequence of drop formation waveforms in which a small-drop waveform applied after another identical small-drop waveform causes a small drop of volume Vs to be formed; applying a small-drop waveform after a large-drop waveform causes a small drop of volume Vs2 to be formed, where V_{S2} is not equal to V_S; applying a large-drop waveform after another identical large-drop waveform causes a large drop of volume VL to be formed, where V_L~N*Vs; and applying a large-drop waveform after a small-drop waveform causes a large drop of volume VL2 to be formed, where V_{L2} is not equal to V_L.

To enable the invention to be better understood, prior art waveforms for the formation of large drops **56** and small drops **54** will first be described, and then waveforms for several embodiments of the invention will be described. FIGS. **5A-5C** show sequences of prior art waveforms. FIG. **5A** shows a sequence of small-drop waveforms **100**. Each of the small-drop waveforms **100** has a period of 1 X_S. (The units of the waveform times scale in this and subsequent waveform figures are in small-drop periods X_S.) The individual small-drop waveforms **100** each include a drop forming pulse **102**, also called a volume controlling pulse. Each drop-forming pulse **102** has a leading edge **104**, a trailing edge **108** and a centroid **106**. The leading edge **104** of the drop forming pulse **102** is at the starting endpoint **130** of the small-drop waveform **100**. As the time from one volume-control pulse **102** to the next is constant, equal to X_S, the application of this sequence of waveforms to the drop forming device **28** causes a sequence of small drops **54** to be formed; each with the same volume. The volume of these small drops **54** is defined to be Vs.

FIG. **5B** shows a sequence of large-drop waveforms **110**. Each of the large-drop waveforms **110** includes the drop forming pulse **102**, and has a period of X_L that is equal to $3X_S$. Each volume-control pulse **112** has a leading edge **114**, a trailing edge **118** and a centroid **116**. The leading edge **104** of the drop forming pulse **102** is at the starting endpoint **130** of the large-drop waveform **100**. The time between successive drop forming pulses **102** is $X_L=3X_S$, three times the time between the drop forming pulses **102** of FIG. **5A**. As the time between successive drop forming pulses **102** is three times the time between the drop forming pulses **102** of FIG. **5A**, the distance on the liquid jet between the pinch points created by the drop forming pulses **102** of the sequence of large-drop waveforms **110** is three times the distance on the liquid jet between the pinch points created by the drop forming pulses **102** of the sequence of small-drop waveforms **100**. As a result, the drops **56** formed by the application of the sequence of large-drop waveforms **110** have volumes, V_L, which are three times the volume of the drops **54** formed by the application of the small-drop waveforms **100**; that is, $V_L=3$ Vs.

FIG. **5C** shows an sequence of waveforms that includes both small-drop waveforms **100** and large-drop waveforms **110**. The small-drop waveforms **100** are same as the small-drop waveforms **100** of FIG. **5A**, and the large-drop waveforms **110** are the same as that of FIG. **5B**. The waveforms **100**, **110** in the sequence have been individually labeled a-i. The drop forming pulses **102**, **112** of these waveforms **100**, **110** each have their leading edges at the starting endpoint **130** of the waveform **100**, **110**. The large drops waveforms **110**, labeled b, f, h, and i, each have periods $X_L=3X_S$, while small-drop waveforms **100**, labeled a, c, d, e, and g, each have periods of X_S. The time interval between the drop forming pulse **112** of waveform b and the drop forming pulse **102**, **112** of the following waveform, waveform c, is equal to X_L; this is three times the time interval between the drop forming pulse **102** of waveform a and the drop forming pulse **112** of waveform b. As a result, waveform b produces a large drop **56** having a volume V_L which is three times the volume Vs of the small drop **54** produced by waveform a. In a similar manner, waveforms f, h, and i produce large drops **56** having volumes V_L that are three times the volume Vs of the small drops **54** produced by waveforms c, d, e, and g.

FIG. **6** shows sequences of waveforms according to an embodiment of the invention. FIG. **6A** shows a sequence of small-drop waveforms **100**. In this embodiment, small-drop waveforms **100** are unchanged from those of the prior art shown in FIG. **5A**. The small-drop waveforms **100** have the same period Xs and same duty cycle as those of FIG. **5A**. Furthermore the leading edge **104** of the drop forming pulse **102** is located at the start or starting endpoint, of each small-drop waveform **100** as was the case in FIG. **5A**. The small drops created by the sequence of small-drop waveforms **100** in FIG. **6A** will therefore have the same volume as small drops **54** produced by the small-drop waveforms **100** of FIG. **5A**; the small drop volume will be Vs.

FIG. **6B** shows a sequence of large-drop waveforms **120**. These large-drop waveforms **120** have the same period X_L as the large-drop waveforms **110** of FIG. **5B**. The duty cycle and amplitude of the drop forming pulses **122** are also unchanged from that of FIG. **5B**. Each drop-forming pulse **122** has a leading edge **124**, a trailing edge **128** and a centroid **126**. The large-drop waveforms **120** differ from the large-drop waveforms **110** of FIG. **5B**. The drop forming pulse **122** has been shifted, delayed within the large-drop waveform **120** so that the leading edge **124** of the drop forming pulse **122** is no longer at the starting endpoint **130** of the large-drop waveform **120**. The center or centroid **126** of the drop forming pulse **122** of the large-drop waveform **120** has been delayed or shifted relative to the start, or starting endpoint **130**, of the large-drop waveform **120** when compared to the centroid **106** of the drop forming pulse **102** of small-drop waveform **100** of FIG. **6A**. As each of the drop forming pulses **120** has been delay by the same amount relative to the starting endpoint **130** of the associated large-drop waveform **120**, the time interval between the drop forming pulses **122** is equal to the period X_L of the large-drop waveform **120**. As a result, the volume of the large drops created by the application of this sequence of large-drop waveforms **120** is equal to the volume of the large drops created by the application of the large-drop waveforms **110** of FIG. **5B**; the volume of the large drops produced by the sequence of large drops waveform **120** of FIG. **6**B is equal to V_L which is equal to 3 times the volume V_S of the small drops produced by the sequence of small-drop waveforms **100** of FIG. **6**A.

FIG. **6**C shows an alternating sequence of small-drop waveforms **100** and large-drop waveforms **120**; the small-drop waveforms **100** being of the type shown in FIG. **6**A and the large-drop waveforms **120** being of the type shown in FIG. **6**B. See also FIG. **7**, which is a close up view of a single small-drop waveform **100** and single large-drop waveform **120** from the sequence in FIG. **6**C. The small-drop waveforms **100** each have the leading edge **104** of the drop forming pulse **102** at the starting endpoint **130** of the small-drop waveform **100**. The centroid **106** of the drop forming pulse **102** is at a first predetermined time T_1 relative to the starting endpoint **130** of the small-drop waveform **100**. The location or timing of the drop forming pulse **122** within the large-drop waveform **120** has been shifted, delayed, so that the leading edge **124** of the drop forming pulse **122** is not at the starting endpoint of the large-drop waveform **120**. Due to this shifting of the drop forming pulse **122** timing, the centroid **126** of the drop forming pulse **122** of the large-drop waveform **120** is at a second predetermined time T_2 relative to the starting endpoint **130** of the large-drop waveform **120**; the second predetermined time being different from the first predetermined time. The time interval T_S between the centroid **106** of the drop forming pulse **102** of the small-drop waveform **100** and the centroid **126** of the drop forming pulse **122** of the following large-drop waveform **120** is not equal to the small-drop period X_S, but rather is larger than that by an amount equal to T_2-T_1. As a result of this increased time between these drop forming pulses **102**, **122**, the small drop that is created has a volume V_{S2} that is larger than volume V_S of the small drop created by consecutive small-drop pulses in FIG. **6**A. On the other hand, the time interval T_L between the centroid **126** of the drop forming pulse **122** of the large-drop waveform **120** and the centroid **106** of the drop forming pulse **102** of the following small-drop waveform **100** is less than X_L by an amount equal to T_2-T_1. The large drop that is produced has a volume V_{L2} that is less than the volume V_L of large drops produced by consecutive large drops waveforms **120** as in FIG. **6**B. By varying the amount by which the timing of the volume-control pulse of the large-drop waveform **120** is shifted, which varies the difference T_2-T_1, the volume difference between V_{L2} and V_L and the volume difference between V_{S2} and V_S can be varied.

FIG. **6**D shows a sequence of waveforms that both small-drop waveforms **100** and large-drop waveforms **120**. The individual waveforms **100**, **120** have been labeled *a-i* to aid in the description. The small-drop waveforms **100** each have the leading edge **104** of the drop forming pulse **102** at the starting endpoint **130** of the small-drop waveform **100**. The centroid **106** of the drop forming pulse **102** is at a first predetermined time T_1 relative to the starting endpoint **130** of the small-drop waveform **100**. The location or timing of the drop forming pulse **122** within the large-drop waveform **120** has been shifted, delayed, so that the leading edge **124** of the drop forming pulse **122** is not at the starting endpoint **130** of the large-drop waveform **120**. Due to this shifting of the drop forming pulse **122** timing, the centroid **126** of the drop forming pulse **122** of the large-drop waveform **120** is at a second predetermined time T_2 relative to the starting endpoint **130** of the large-drop waveform **120**; the second predetermined time being different from the first predetermined time. Just like the small-drop waveforms **100** of FIG. **6**C were followed immediately thereafter by a large-drop waveform **120**, the small-drop waveforms **100** labeled *a, e*, and *g* are each are followed immediately thereafter by a large-drop waveform **120**. The time interval between the centroid **106** of the drop forming pulse **102** of the small-drop waveform **100** for each of these small-drop waveforms **100**, a, e, and g, and the centroid **126** of the drop forming pulse **122** of the following large-drop waveform **120** is not equal to the small-drop period X_S, but rather is larger than that by an amount equal to T_2-T_1. As a result, the volume of the small drop that is created is not equal to V_S but rather is equal to V_{S2}; where $V_{S2}>V_S$. Just as the large-drop waveforms **120** of FIG. **6**C were followed immediately thereafter by a small-drop waveform **100**, the large-drop waveforms **120** b, f, and i are followed immediately thereafter by small-drop waveforms **100** c, g, and j. The time interval between the centroid **126** of the drop forming pulse **122** of a large-drop waveform **120** for each of these large-drop waveforms **120**, b, f, and i, and the centroid **106** of the drop forming pulse **102** of the following small-drop waveform **100** is less than X_L by an amount equal to T_2-T_1. The large drop that is produced has a volume V_{L2}, like those produced by the large-drop waveforms **120** in FIG. **6**C. This volume is less than volume V_L of large drops produced by consecutive large drops waveforms **120** as in FIG. **6**B. Small-drop waveform **100***b* immediately precedes small-drop waveform **100***d*, and small-drop waveform **100** immediately precedes small-drop waveform **100***e*. The time interval between the drop forming pulse **102** of small-drop waveform **100***c* and the drop forming pulse **102** of small-drop waveform **100***d* is equal to the X_S, as is the time between the drop forming pulse **102** of small-drop waveform **100***d* and the drop forming pulse **102** of small-drop waveform **100***e*. As this time interval equals that between the drop forming pulses **102** of the small-drop waveforms **100** in FIG. **6**A, the volume of the drops created by these time intervals between drop forming pulses **102** is equal to V_S. Large-drop waveform **120** *h* immediately precedes large-drop waveform i. The time interval between the drop forming pulses **122** of these two large-drop waveforms **120** is equal to X_L, where $X_L=3X_S$. The resulting drop therefore as a volume VL, where $V_L=3V_S$.

For this embodiment, delaying the drop forming pulse **122** within the large-drop waveform **120** caused the centroid **126** of the drop forming pulse **122** to be at a time interval T_2 relative to the starting endpoint **130** of the large-drop waveform **120**. This time interval is different from the time interval T_1 between the centroid **106** of the drop forming pulse **102** of the small-drop waveform **100** and the starting endpoint **130** of the small-drop waveform **100**. When consecutive small-drop waveforms **100** are applied to the drop forming mechanism **28**, a small drop of volume V_S is formed. When consecutive large-drop waveforms **120** are applied to the drop forming mechanism **28**, a large drop of volume VL is formed, where $V_L=3V_S$. Applying a large-drop waveform **120** immediately after a small-drop waveform **100** causes a small drop to be formed having a volume V_{S2}, which is different from V_S. Applying a small-drop waveform **100** immediately after a large-drop waveform **120** produces a large drop having a volume V_{L2}, which is different from V_L. In this embodiment, the volume V_{S2} is larger than V_S, and the volume V_{L2} is less than V_L.

In the embodiment described above, the timing of the drop forming pulse **122** of the large-drop waveform **120** was shifted so that the leading edge of the drop forming pulse **122** was not at the starting endpoint **130** of the large-drop waveform **120**, while the leading edge of the drop forming pulse **102** of the small-drop waveform **100** was at the starting endpoint **130** of the small-drop waveform **100**. As described above, this reduced the volume of a large drop created by a large-drop waveform **120** followed by a small-drop waveform **100**; $V_{L2}<V_L$, and increased the volume of a small drop created by a small-drop waveform **100** followed by a large-drop waveform **120**; $V_{S2}>V_S$. In an alternate embodiment shown in FIG. **8**, the drop forming pulse **142** of the small-drop waveform **140** is delayed instead of the drop forming pulse **152** of the large-drop waveform **150**. The leading edge **144** of the drop forming pulse **142** of the small-drop waveform **140** is not at the starting endpoint **130** of the small-drop waveform **140**, but the leading edge **154** of the drop forming pulse **152** of the large-drop waveform **150** is at the starting endpoint **130** of the large-drop waveform **150**. The centroid **146** of the drop forming pulse **142** of the small-drop waveform **140** is at a first time interval T_1 relative to the starting edge **130** of the small-drop waveform **140**. The centroid **156** of the drop forming pulse **152** of the large-drop waveform **150** is at a second time interval T_2 relative to the starting edge **130** of the large-drop waveform **150**. The second time interval T_2 is different from the first time interval T_1. In this embodiment, the first time interval T_1 is greater than the second time interval T_2. When consecutive small-drop waveforms **140** are applied to the drop forming mechanism **28**, a small drop of volume V_S is formed. When consecutive large-drop waveforms **150** are applied to the drop forming mechanism **28** a large drop of volume V_L is formed, where $V_L=3V_S$. When a large-drop waveform **150** is applied immediately after a small-drop waveform **140**, the time interval T_S between the centroid **146** of the drop forming pulse **142** of the small-drop waveform **140** and the centroid **156** of the drop forming pulse **152** of the following large-drop waveform **150** is not equal to the small-drop period X_S; $T_S<X_S$. As a result, the small drop that is formed has a volume V_{S2}, which is different from V_S. Similarly applying a small-drop waveform **140** immediately after a large-drop waveform **150** produces a large drop having a volume V_{L2}, which is different from V_L. In this embodiment, the volume V_{S2} is smaller than V_S, and the volume V_{L2} is greater than V_L.

In the embodiments of the invention described above, the leading edge of drop forming pulse or volume-control pulse of either the small-drop waveform or the large-drop waveform was at the starting endpoint of the waveform, while the volume-control pulse of the other of the small-drop waveform or the large-drop waveform was delayed so that the leading edge of the delayed volume-control pulse was not at the starting endpoint of the corresponding waveform. The centroid of the drop forming pulse of the small-drop waveform is at a first time interval T_1 relative to the starting edge of the small-drop waveform. The centroid of the drop forming pulse of the large-drop waveform is at a second time interval T_2 relative to the starting edge of the large-drop waveform. The second time interval T_2 is different from the first time interval T_1. FIG. **9** shows another embodiment, in which the trailing edge **168** or **178** of the volume-control pulse of either the small-drop waveform **160** or the large-drop waveform **170**, respectively, was at the trailing endpoint **130** of the waveform **160**, **170**, while the drop forming pulse **162**, **172** of the other of the small-drop waveform **160** or the large-drop waveform **170** was advanced so that the trailing edge **168**, **178** of the advanced drop forming pulse **162**, **172** was not at the trailing endpoint **130** of the corresponding waveform **160**, **170**. In this embodiment, the centroid **166** of the drop forming pulse **162** of the small-drop waveform **160** is at a first time interval T_1 measured relative to the trailing endpoint **130** rather than the starting endpoint **130** of the small-drop waveform **160**. In this example, the trailing endpoint is in the predetermined endpoint. The centroid **176** of the drop forming pulse **172** of the large-drop waveform **170** is at a second time interval T_2 relative to the trailing endpoint **130** of the large-drop waveform **170**. The second time interval T_2 is different from, larger than, the first time interval T_1. In this embodiment, the timing of the drop-forming pulse **172** of the large-drop waveform **170** and of drop-forming pulse **162** of the small-drop waveform **160** are both measured from the trailing point **130** of the respective waveforms. The trailing endpoint **130** of the small-drop waveform **160** in this embodiment serves as a predefined endpoint from which to measure the timing of the pulse. The timing of the pulse of the large-drop waveform **170** is measured from the corresponding endpoint **130** to the predefined endpoint **130** of the small-drop waveform **160**, in that the timing of the drop-forming pulse **172** of the large-drop waveform **170** is also measured from the trailing endpoint **130**. If the predefined endpoint of the small-drop waveform **160** is the trailing endpoint **130** of the small-drop waveform **160** the corresponding endpoint of the large-drop waveform **170** is also the trailing endpoint **130** of the large-drop waveform **170**. On the other hand, as was done in the embodiment of FIG. **8**, where the predefined endpoint **130** of the small-drop waveform **140** from which to time the drop-forming pulse **142** of the small-drop waveform **140** is the starting endpoint of the small-drop waveform **140**, then the corresponding endpoint of the large-drop waveform **150** is the starting endpoint of the large-drop waveform **150** relative to which the timing of the drop-forming pulse **152** of the large-drop waveform **150** is measured. Returning to the embodiment of FIG. **9**, the trailing endpoint **130** of the large drop waveform **170** corresponds to the trailing endpoint **130** of the small drop waveform **160**. When a large-drop waveform **170** is applied immediately after a small-drop waveform **160** as in large-drop waveform **170***b*, the time interval T_L between the centroid **166** of the drop forming pulse **162** of the small-drop waveform **160** and the centroid **176** of the drop forming pulse **172** of the following large-drop waveform **170** is not equal to the small-drop period X_L. As a result, the large drop that formed has a volume V_{L2}, which is different from V_L. Similarly applying a small-drop waveform **160** immediately after a large-drop waveform **170** produces a small drop having a volume V_{S2}, this is different from V_S. In this embodiment, the volume V_{S2} is greater than V_S, and the volume V_{L2} is less than V_L. This embodiment like the previous ones enables drops to be created with drop volumes V_S, V_{S2}, V_L, and V_{L2}, where $V_L=3*V_S$, V_{S2} is different from V_S, and V_{L2} is different from V_L.

FIG. **10** shows another embodiment of the invention. This embodiment has a set of waveforms in which the small-drop waveform **180** or the large-drop waveform **190** have the leading edges **184** and **194** and the trailing edges **188** and **198** of the drop-forming pulses **182** and **192**, respectively are located away from both the starting endpoint and the trailing endpoint of the corresponding waveform **180**, **190**. In this embodiment, the centroid **186** of the drop forming pulse **182** of the small-drop waveform **180** is at a first time interval T_1 relative to the one of the endpoints of the small-drop waveform **180** and the centroid **186** of the drop forming pulse **192** of the large-drop waveform **190** is at a second time interval T_2 relative to the corresponding endpoint of the large-drop waveform **190**; and where the second time interval T_2 is different from the first time interval T_1. When a large-drop waveform **190** is applied immediately after a small-drop waveform **180** as in large-drop waveform **190** *b*, the time interval T_L between the centroid **186** of the drop forming pulse **182** of the small-drop waveform **180** and the centroid **196** of the drop forming pulse **192** of the following large-drop waveform **190** is not equal to the small-drop period X_L. As a result, the large drop that formed has a volume V_{L2}, which is different from V_L. Similarly, applying a small-drop waveform **180** immediately after a large-drop waveform **190**, as in small-drop waveform **180** *c*, produces a small drop having a volume V_{S2}, which is different from V_S. In this embodiment, the volume V_{S2} is greater than V_S, and the volume V_{L2} is less than V_L. This embodiment like the previous ones enables drops to be created with drop volumes V_S, V_{S2}, V_L, and V_{L2}, where $V_L=3*V_S$, V_{S2} is different from V_S, and V_{L2} is different from V_L.

In each of these embodiments, varying the amount by which the timing of the drop-forming pulse of the small-drop waveform and/or of the large-drop waveform is shifted varies the difference T_2-T_1, the volume difference between V_{L2} and V_L and the volume difference between V_{S1} and V_S can be varied. By appropriate selection of the timing of the drop-forming pulses, the volume difference between the small drop V_{S2} and small drop volume V_S, $|V_{S2}-V_S|$ can be selected to be greater than of $0.03*V_S$, or greater than $0.05*V_S$, or greater than and $0.1*V_S$. It tends not to be practical to adjust the drop-forming pulse timings to produce a volume difference between the small drop V_{S2} and small drop volume V_S, $|V_{S2}-V_S|$, of greater than $0.3*V_S$.

The embodiments described above have a large-drop waveform with a period of X_L which is equal to three times the period X_S of the small-drop waveform. When consecutive large-drop waveforms are applied, the resulting large drop has a volume $V_L=3*V_S$. The invention is not limited to a factor of three in waveform periods between the large-drop waveforms and the small-drop waveforms. In general, the ratio between the large-drop waveform period and the small-drop waveform period can be any integer value. The ratio in the periods will be denoted by N. In the more generalized form, the consecutive small-drop waveforms produce small drops of volume V_S, and consecutive large-drop waveforms produce large drops of volume V_L, where $V_L=N*V_S$. Applying a large-drop waveform immediately after a small-drop waveform causes a small drop to be formed having a volume V_{S2}, which is different from V_S. Applying a small-drop waveform immediately after a large-drop waveform produces a large drop having a volume V_{L2}, which is different from V_L.

U.S. Pat. No. 8,087,740 discloses that drop formation pulses can be composed of a packet of sub-pulses. This is effective when the time between the sub-pulses is less than the response time of the drop forming device, for example when the time between the sub-pulses is less than the thermal response time of heater used as a drop forming device. In such cases, the packet of sub-pulses acts on the liquid jet as a single pulse having a leading edge corresponding to the leading edge of the first sub-pulse in the packet and a trailing edge corresponding to the trailing edge of the last sub-pulse in the packet. The centroid of the drop-forming pulse in such cases corresponds to the centroid of the integrated packet of the sub-pulses rather than to centroid of one of the sub-pulses.

The present invention permits the drop volume of the large drops and the small drops to be adjusted. In some embodiments, a plurality of sets of small-drop waveforms and large-drop waveforms are defined, each set of defined waveforms producing different print drop volumes. In one embodiment, one of the sets of small-drop waveforms and large-drop waveforms is selected and employed for printing based at least in part on the desired print drop volume. On another embodiment the flow rate of ink through the printhead nozzles is measured. Based at least in part on the measured flow rate a set of waveforms is selected for use in the printhead from the plurality of defined sets of small-drop waveforms and large-drop waveforms. In some embodiments, the selected set of waveforms is stored in the printhead. In other embodiments, the plurality of defined sets of small-drop waveforms and large-drop waveforms, are stored in memory of the printing system controller.

In another embodiment, the invention is used to reduce coverage variations across the printhead nozzle array produced by variations is nozzle geometry. From the plurality of defined sets of waveforms, one set of small-drop waveforms and large-drop waveforms is used to create drops from a first portion of the nozzle array, and a second set of small-drop waveforms and large-drop waveforms is used to create drops from a second portion of the nozzle array.

It has been found that the invention, by altering the volume of the print drop, alters the momentum of the print drop. As a result of the change in momentum of the print drop the deflection of the print drop by the drop deflection mechanism can be altered. As a result the impact location of the print drop on the print media can be altered. By appropriate use of the drop volume altering waveforms, fine adjustments can be made to the width of character strokes for improved image quality purposes. In some embodiments of the invention, the set of waveforms used for printing can include a small drop waveform and a first large-drop waveform and a second large-drop waveform. The second large-drop waveform has a period equal to the period of the first large-drop waveform, the second large-drop waveform including a large-drop forming pulse, wherein the waveform of the second large-drop waveform is distinct from the waveform of the first large-drop waveform. In certain embodiments, the centroid **186** of the drop forming pulse of the small-drop waveform is at a first time interval T_1 relative to the one of the endpoints of the small-drop waveform and the centroid **186** of the drop forming pulse of the first large-drop waveform is at a second time interval T_2 relative to the corresponding endpoint of the large-drop waveform; and where the second time interval T_2 is different from the first time interval T_1. The second large-drop waveform has a drop forming pulse having a centroid at a third time interval T_3 relative to the corresponding endpoint of the second large-drop waveform. The third time interval T_3 is different from the second time interval T_2.

In some embodiments of the invention, the set of waveforms used for printing can include a first small-drop waveform and a second small-drop waveform and a large-drop waveform. The second small-drop waveform has a period equal to the period of the first small-drop waveform, the second small-drop waveform including a small-drop volume-control pulse. The waveform of the second small-drop waveform is distinct from the waveform of the first small-drop waveform. The centroid **186** of the drop forming pulse of the first small-drop waveform is at a first time interval T_1 relative to the predetermined one of the starting endpoint and the trailing endpoint of the small-drop waveform, centroid **186** of the drop forming pulse of the second small-drop waveform is at a third time interval T_3 relative to the corresponding one of the starting endpoint and the trailing endpoint of the second small-drop waveform and the centroid **186** of the drop forming pulse of the large-drop waveform is at a second time interval T_2 relative to the corresponding starting endpoint and the trailing endpoint of the large-drop waveform.

Similarly in some embodiments of the invention the set of waveforms used include a first small-drop waveform and a second small-drop waveform and a large-drop waveform. The second large-drop waveform has a period equal to the period of the first large-drop waveform, the second large-drop waveform including a large-drop volume-control pulse. The waveform of the second large-drop waveform is distinct from the waveform of the first large-drop waveform. The centroid **186** of the drop forming pulse of the first large-drop waveform is at a first time interval T_1 relative to the predetermined one of the starting endpoint and the trailing endpoint of the first large-drop waveform and the centroid **186** of the drop forming pulse of the second large-drop waveform is at a second time interval T_2 relative to the corresponding one of the starting endpoint and the trailing endpoint of the second large-drop waveform, and the centroid of the drop forming pulse of the small drop waveform is at a third time interval relative to the corresponding one of the starting endpoint and the trailing endpoint of the small-drop waveform. The use of multiple large-drop waveforms or multiple small-drop waveforms provides more flexibility in terms of the amount of ink that can be printed on a pixel.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

20 Continuous Printer System
22 Image Source
24 Image Processing Unit
26 Mechanism Control Circuits
27 Drop Formation Waveforms
28 Drop Forming Mechanism
30 Printhead
32 Recording Medium
34 Recording Medium Transport System
36 Recording Medium Transport Control System
38 Micro-Controller
40 Reservoir
42 Catcher
44 Recycling Unit
46 Pressure Regulator
47 Channel
48 Jetting Module
49 Nozzle Plate
50 Plurality of Nozzles
51 Heater
52 Liquid
54 Drops
56 Drops
57 Trajectory
58 Drop Stream
60 Gas Flow Deflection Mechanism
61 Positive Pressure Gas Flow Structure
62 Gas Flow
63 Negative Pressure Gas Flow Structure
64 Deflection Zone
66 Small Drop Trajectory
68 Large Drop Trajectory
72 First Gas Flow Duct
74 Lower Wall
76 Upper Wall
78 Second Gas Flow Duct
82 Upper Wall
84 Seal
86 Liquid Return Duct
88 Plate
90 Front Face
92 Positive Pressure Source
94 Negative Pressure Source
96 Wall
98 Waveform Source
100 Small-drop Waveform
102 Drop forming Pulse
104 Leading edge
106 Centroid
108 Trailing Edge
110 Large-Drop waveform
112 Drop Forming Pulse
114 Leading edge
116 Centroid
118 Trailing Edge
120 Large-Drop Waveform
122 Drop-Forming Pulse
124 Leading edge
126 Centroid
128 Trailing Edge
130 Endpoint
140 Small-Drop Waveform
142 Drop-Forming Pulse
144 Leading edge
146 Centroid
150 Large-Drop Waveform
152 Drop-Forming Pulse
154 Leading edge
156 Centroid
160 Large-Drop Waveform
162 Drop-Forming Pulse
166 Centroid
168 Trailing Edge
170 Large-Drop Waveform
172 Drop-Forming Pulse
176 Centroid
178 Trailing Edge
180 Large-Drop Waveform
182 Drop-Forming Pulse
184 Leading edge
186 Centroid
188 Trailing Edge
190 Large-Drop Waveform
192 Drop-Forming Pulse
194 Leading edge
196 Centroid
198 Trailing Edge

The invention claimed is:

1. A method for operating a jetting module comprising:

providing a jetting module including a nozzle and a drop forming mechanism;

providing a liquid to the jetting module under pressure sufficient to cause a liquid stream to jet from the nozzle;

providing a small-drop waveform, the small drop waveform having a starting endpoint and a trailing endpoint, the small-drop waveform having a small-drop period X_S equal to the time between the starting endpoint and the trailing endpoint of the small-drop waveform, the small-drop waveform including a small drop volume-control pulse, the small-drop volume-control pulse of the small-drop volume-control pulse having centroid, the centroid of the small-drop volume-control pulse being at a first defined time relative to a predefined one of the starting endpoint and the trailing endpoint of the small-drop waveform;

providing a large-drop waveform, the large-drop waveform having a starting endpoint and a trailing endpoint, the large-drop waveform having a large-drop period X_L, where $X_L=N*X_S$ and N is an integer greater than one, the large-drop waveform including a large-drop volume-control pulse, the large-drop volume-control pulse having centroid, the large-drop waveform having a corresponding endpoint that corresponds to the predetermined endpoint of the small-drop waveform;

wherein the centroid of the large-drop volume-control pulse being at a second defined time relative to the corresponding one of the starting endpoint and trailing endpoint of the large-drop waveform, the second defined time being different from the first defined time;

applying to the drop forming mechanism a sequence of drop formation waveforms in which:

applying a small-drop waveform after another identical small-drop waveform causes a small drop of volume Vs to be formed;

applying a small-drop waveform after a large-drop waveform causes a small drop of volume Vs2 to be formed, where V_{S2} is not equal to V_S;

applying a large-drop waveform after another identical large-drop waveform causes a large drop of volume VL to be formed, where V_L~N*Vs; and

applying a large-drop waveform after a small-drop waveform causes a large drop of volume VL2 to be formed, where V_{L2} is not equal to V_L.

2. The method as in claim **1**, wherein the relationship between the small drop volume V_{S2} and the small drop volume V_S is given by $|V_{S2}-V_S|$ is between $0.03*V_S$ and $0.3*V_S$.

3. The method as in claim **2**, wherein the relationship between the small drop volume V_{S2} and the small drop volume V_S is given by $|V_{S2}-V_S|$ is between $0.05*V_S$ and $0.3*V_S$.

4. The method as in claim **3**, wherein the relationship between the small drop volume V_{S2} and the small drop volume V_S is given by $|V_{S2}-V_S|$ is between $0.1*V_S$ and $0.3*V_S$.

5. The method of claim **1** wherein a plurality of sets of small-drop waveforms and large-drop waveforms are defined, each set of defined waveforms producing different print drop volumes, and one set of waveforms is selected and employed based at least in part on the desired print drop volume.

6. The method of claim **1** wherein a plurality of sets of small-drop waveforms and large-drop waveforms are defined, each set of waveforms producing different print drop volumes, wherein one set of the waveforms sets is stored on the jetting module, the stored waveform set being selected based at least in part on the flow rate of ink through the jetting module nozzle.

7. The method of claim **1** the nozzle of the jetting module is a nozzle in an array of nozzles on the jetting module wherein one set of small-drop waveforms and large-drop waveforms is used to create drops from a first portion of the nozzle array, and a second set of small-drop waveforms and large-drop waveforms is used to create drops from a second portion of the nozzle array, the first and second sets of waveforms being selected to reduce the coverage variations across the nozzle array.

8. The method of claim **1** wherein the large-drop waveform comprises a plurality of pulses, one of which is the large-drop volume-control pulse.

9. The method of claim **1** wherein the small-drop waveform comprises a plurality of pulses, one of which is the small-drop volume-control pulse.

10. The method of claim **1**, wherein the predefined endpoint comprises the trailing endpoint of the waveform.

11. The method of claim **1**, wherein the predefined endpoint comprises the starting endpoint of the waveform.

12. The method of claim **1** wherein the large-drop waveform comprising a first large-drop waveform and the method further comprising providing a providing a second large-drop waveform that causes the liquid stream to break up to form a large-volume drop, the second large-drop waveform having a period equal to the period of the first large-drop waveform, the second large-drop waveform including a large-drop volume-control pulse, wherein the waveform of the second large-drop waveform is distinct from the waveform of the first large-drop waveform.

13. The method of claim **12** wherein the second large-drop waveform has an endpoint that corresponds to the predefined endpoint of the small-drop waveform, the large-drop volume-control pulse of the second large-drop waveform is pulsed at a third defined time relative to the corresponding endpoint of the second large-drop waveform, the third defined time is different from the second defined time.

14. The method of claim **1** wherein the small-drop waveform comprises a first small-drop waveform, the method further comprising providing a second small-drop waveform that causes the liquid stream to break up to form a second small-volume drop when applied to the drop forming mechanism, the second small-drop waveform including a small-drop volume-control pulse, the second small-drop waveform having a period that equals the period of the first small-drop waveform, the second small-drop waveform being distinct from the first small-drop waveform.

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